



**US Army Corps  
of Engineers®**  
Engineer Research and  
Development Center

**ERDC**  
INNOVATIVE SOLUTIONS  
for a safer, better world

*Center for the Advancement of Sustainability Innovations (CASI)*

## **Assessment of Small Arms Munitions Impacts on Natural Infrastructure in Sensitive Downrange Areas on Military Installations**

David Delaney, Patrick Guertin, Michael White, and Richard Fischer

February 2016



**The U.S. Army Engineer Research and Development Center (ERDC)** solves the nation's toughest engineering and environmental challenges. ERDC develops innovative solutions in civil and military engineering, geospatial sciences, water resources, and environmental sciences for the Army, the Department of Defense, civilian agencies, and our nation's public good. Find out more at [www.erdclibrary.usace.army.mil](http://www.erdclibrary.usace.army.mil).

To search for other technical reports published by ERDC, visit the ERDC online library at <http://acwc.sdp.sirsi.net/client/default>.

# **Assessment of Small Arms Munitions Impacts on Natural Infrastructure in Sensitive Downrange Areas on Military Installations**

David Delaney, Patrick Guertin, Michael White, and Richard Fischer

*U.S. Army Engineer Research and Development Center (ERDC)  
Construction Engineering Research Laboratory (CERL)  
2902 Newmark Dr.  
Champaign, IL 61824*



Final Report

Approved for public release; distribution is unlimited.

Prepared for Headquarters, U.S. Army Corps of Engineers  
Washington, DC 20314-1000

## **Abstract**

Large areas of high-quality terrestrial natural infrastructure exist downrange of small arms training ranges on Department of Defense (DoD) installations. Live-fire training has caused concern to regulatory agencies because of the potential impacts on natural resources, and to safety concerns expressed by adjoining landowners. This report investigated methods to quantify the number of bullets that escape the containment berm and terminate down range. Inquiries were made among Natural Resource peers and reviewed methods that address bullet fate on ranges. Responses to the inquiries indicate that Natural Resource personnel on military facilities, as well as those at other state or federal agencies, do not have adequate tools or guidance to address the potential issue of smalls arms munition impacts within sensitive downrange areas. It was concluded that both acoustical and visual techniques have potential for quantifying bullet overshoot and ricochets into sensitive wildlife areas, though neither approach is sufficiently developed. Acoustical techniques can quantify bullet intrusions into downrange areas. Visual and 3-D analyses can estimate the likelihood for intrusions downrange, but only more comprehensive development and testing would reveal the effectiveness of these techniques at ranges under different field conditions.

# Contents

<b>Abstract .....</b>	<b>ii</b>
<b>Illustrations .....</b>	<b>iv</b>
<b>Preface .....</b>	<b>v</b>
<b>1 Introduction.....</b>	<b>1</b>
1.1 Background .....	1
1.2 Objectives.....	2
1.3 Approach .....	2
<b>2 Data Query across DoD .....</b>	<b>3</b>
2.1 Questions .....	3
2.2 Responses.....	3
2.2.1 Question 1 .....	3
2.2.2 Question 2 .....	4
2.2.3 Question 3 .....	4
2.2.4 Question 4 .....	4
2.2.5 Question 5 .....	5
<b>3 Technology Review .....</b>	<b>6</b>
3.1 Environmental technology/techniques.....	6
3.2 Natural resource technology/techniques.....	7
3.3 Non-environmental technology/techniques .....	8
<b>4 Future Technologies .....</b>	<b>9</b>
4.1 Remote sensing and 3-D visualization .....	9
4.2 Acoustical monitoring .....	9
<b>5 Benefits.....</b>	<b>10</b>
<b>6 Conclusions and Findings .....</b>	<b>12</b>
<b>Acronyms and Abbreviations .....</b>	<b>14</b>
<b>References .....</b>	<b>15</b>
<b>Appendix A: Effects of Bullet Strikes on Fort Benning and Fort Stewart, GA. ....</b>	<b>17</b>
<b>Report Documentation Page (SF 298) .....</b>	<b>20</b>

# Illustrations

## Figures

A-1	Initial horizontal trajectory of a tracer bullet fired at a 600 m target at the Malone 5 range on Fort Benning, GA.....	17
A-2	Path of the same tracer round fired in Fig. A1 that ricochets after hitting the ground near a 600 m target at the Malone 5 range on Fort Benning, GA. Note the upward trajectory of the bullet.....	17
A-3	A formerly active Red-cockaded woodpecker nest tree killed in by wildfire in 2010.....	18
A-4	Different types of tree damage caused by bullet strikes on Fort Benning and Fort Stewart, GA. Multiple forms of tree damage was observed: small scars (A), large cambium cuts (B), bark bullet strikes (C), nodules (D), and broken branches, leader or stems (E) .....	19
A-5	Bullet strike into the bark of a Red-cockaded Woodpecker (RCW) cavity tree approximately 1810 m downrange from the firing line at Malone 5 on Fort Benning, GA.....	19

## Preface

This study was performed under the Center for the Advancement of Sustainability Innovations (CASI). CASI was established by the U.S. Army Engineer Research and Development Center (ERDC) as a new capability in 2006, hosted at the Construction Engineering Research Laboratory (CERL) in Champaign, IL. CASI's mission is to focus ERDC expertise, technologies and partnerships toward helping the U.S. Army Corps of Engineers (USACE), the Army, and the Department of Defense (DoD) achieve more sustainable missions, facilities, and operations. The technical monitor and Associate Director of CASI was Franklin H. Holcomb.

The work was managed and executed by the Ecological Processes Branch (CN-N) of the Installations Division (CN), Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL). The CERL principal investigator was David Delaney. At the time of publication, Dr. Christopher Rewerts was Acting Chief, CN-N, and Michelle Hanson was Chief, CN. The associated Technical Director was Alan Anderson, CV-T. The Deputy Director of CERL is Dr. Kirankumar Topudurti and the Director of CERL is Dr. Ilker R. Adiguzel.

COL Bryan S. Green was Commander of ERDC, and Dr. Jeffery P. Holland was the Director.





# 1 Introduction

## 1.1 Background

Large areas of high-quality terrestrial natural infrastructure (including critical habitat, sensitive species, and commercially valuable resources) exist downrange of small arms training ranges on Department of Defense (DoD) installations. Historically, live-fire training has caused concern to regulatory agencies (e.g., U.S. Environmental Protection Agency [USEPA], and U.S. Fish and Wildlife Service [USFWS]) because of the potential impacts that downrange munitions might have on natural resources, such as: (1) constituent contamination, (2) wild fire ignition, (3) damage to critical habitat, and (4) impacts on listed species. Projectiles escape the containment area primarily through overshoot and ricochet. Such unavoidable occurrences on small arms training ranges make it impossible to adequately judge the effectiveness of berms and other forms of mitigation, and thereby expose natural infrastructure to potential damage. Additionally, bullet strikes on commercially salable trees degrade their value, and in some cases cause adjoining land owners to express safety concerns.

In terms of quantifying this phenomenon, methodology exists to implement Surface Danger Zones (SDZs) that estimate the probability of injury (i.e., both human and non-human) or damage to property, but not to estimate the long-term likelihood of occurrence of projectile deposition area density. In terms of qualifying potential impacts of bullets downrange, few studies have attempted to quantify or characterize live-fire training events (e.g., number of rounds fired, timing of firing events, bullet fate, and areas of bullet concentration) and corresponding tree damage downrange. Some preliminary work has documented the presence of bullet damage in downrange Red-cockaded Woodpecker (RCW, *Picoides borealis*) habitat on southeastern military installations (Delaney et al. 2011a,b). Another recent study (Applegate 2005) documented general land conditions downrange of an active live-fire range. Such data would support the effective management of Threatened and Endangered Species (TES) populations to meet military conservation requirements, and these data would offer information necessary to mitigate for future changes in land management needs associated with military training doctrine.

## **1.2 Objectives**

This document reports on an investigation to determine whether there are reliable documented methods to quantify the number of bullets that escape the containment berm and end up down range. This document also proposes ways to address this problem.

## **1.3 Approach**

The objectives of this work were realized in the following steps:

1. Informal queries were conducted among Natural Resource peers across DoD to better assess undocumented issues of downrange bullet impacts and mitigation strategy in use.
2. Technology and methods that address bullet fate on ranges were reviewed.
3. Potential avenues of dedicated research were identified.

## **2 Data Query across DoD**

### **2.1 Questions**

Through contacts across DoD Services, input was gathered from installation and command level offices, and from other Federal and State offices referred to this study. The methodology took the form of an informal data inquiry (questionnaire) comprised of five questions:

1. Who are the stakeholders involved in downrange installation issues?
2. What installation-specific issues are identifiable to help outline the broader categories that are a concern for installations?
3. What species of concern (flora and fauna) are downrange from live-fire military training ranges?
4. What installation plans or accomplishments (i.e., specific techniques, technology) are available and/or being implemented to reduce the impacts of munitions entering sensitive natural areas downrange (e.g., build full or partial berms, use of witness panels to assess bullet overshoot, construct Shock-Absorbing Concrete (SACON™) barriers or remove skid plates around target coffins to reduce ricochets. See Appendix A, Figures A-1 and A-2.)
5. What methods (technology or techniques) are being used to assess the effects of munitions on downrange natural resources?

### **2.2 Responses**

Seventeen responses to the inquiries were received from military installations, research laboratories, and affiliated state and federal organizations representing the U.S. Navy, U.S. Marine Corps, U.S. Army, Army National Guard, U.S. Air Force, and U.S. Fish and Wildlife Service. The responses varied considerably by installation, base, organization, and agency. This variation is not surprising considering the different missions/goals covered within DoD.

#### **2.2.1 Question 1**

Responses varied depending on installation and issue. In general, respondents identified government stakeholders and private interest groups. For the most part, Government stakeholders are State and Federal agencies involved in compliance activities. These include environmental protection agencies (USEPA and its state EPA counterparts) and Natural Resource agencies (i.e., USFWS and State Departments of Natural Resources

[DNRs]) that oversee Federal and State listed species concerns. Government agencies that hold adjoining lands are also stakeholders (regarding concerns for the fate of munitions off range) are some were included in the query. Non-government stakeholders represent national and local level groups that primarily focus on natural resources conservation issues.

### **2.2.2 Question 2**

Answers varied across responses, but respondents generally identified the following issues:

1. Environmental contamination caused by expended military munitions that disperses across areas as ground/surface water and soil contamination, and results in lead mobility through the environment
2. Noise
3. Wildfire risk from natural or military caused events, such as from incendiary devices or munitions (i.e., tracer rounds; see Appendix A, Figure A-3)
4. Tree damage, which can reduce timber value or impact wildlife habitat (see Appendix A, Figure A-4)
5. Compromised access to downrange areas for wildlife surveys, invasive species surveys and eradication/restoration efforts, cemetery monitoring, site maintenance.
6. Species conflicts with range use
7. Increased requirements for coordination due to species presence.

### **2.2.3 Question 3**

Answers generally identified federally listed species across multiple taxa, including birds, mammals, reptiles, amphibians, and insects.

### **2.2.4 Question 4**

Answers were uniform across the majority of replies. Mitigation strategies are concentrated into two areas: (1) contaminants (lead), and (2) bullet impact (i.e., habitat damage and fire).

Contaminant issues are generally addressed through DoD recognized Best Management Practices (BMPs) and monitoring with test wells, when required, on ranges both with and without berms. For non-contaminant issues, active ranges generally use berms, whereas future construction includes planning considerations (following Service BMPs). Respondents indicated that some ranges do not have berms to contain bullets, but instead rely on natural

slopes over distance. One respondent said that the need for a berm is determined based on the presence of TES suitable habitat downrange.

### **2.2.5 Question 5**

Answers referred only to aerial photo and down-range site surveys. Respondents cited the use of aerial photo interpretation to examine general trends in vegetation changes due to impacts. Respondents included visual surveys and witness boards to examine finer scale impacts, such as bullet strikes and tree mortality. None of the respondents indicated that they had attempted to quantify numbers of rounds that went past berms. Among respondents, an assumption is that berms stop a majority (95%) of rounds from leaving the target area. (See Delaney et al. 2011b.) A few respondents wanted to better understand the fate of small arms munitions.

### 3 Technology Review

This work considered technologies to quantify downrange impacts of small arms munitions of firing ranges in three categories:

- *Environmental technologies*, defined as protocols and methodologies that encompass environmental issues such as munition constituents. They focus on compliance issues such as groundwater contamination.
- *Natural resource technologies*, defined as protocols and methodologies that capture impacts on plant and soil components of the natural infrastructure. Examples include tree health surveys that account for damage to habitat and methods to quantify soil erosion.
- *Non-environmental technologies*, defined as construction methods (berms, special materials) and construction planning tools used to design and build to mitigate bullet impacts.

#### 3.1 Environmental technology/techniques

Past research in small arms range impacts focused on munitions constituent contamination, with a lesser focus on erosion, and range design considerations for compliance (e.g., Heath et al. 1991). Results include planning and management tools (computer software) or written documentation as in BMPs and research reports. Examples of documentation include: (1) work sponsored by the U.S. Army Environmental Command (USAEC), including the *Army Small Arms Training Range Environmental BMP Manual* (Fabian 2006), (2) the *Range Design Risk Assessment Model*,\* which is a web based tool to identify environmental compliance issues related to range design, and (3) *Environmental Management at Operating Outdoor Small Arms Firing Ranges* (ITRC 2005).

ERDC has conducted research in areas of environmental contamination, including the Training Range Environmental Evaluation and Characterization System (TREECS™). TREECS™ is a tool for forecasting the risk of munitions constituents (MC), such as high explosives and metals, that leave firing and training ranges and contaminate the environment (Gerald et al. 2009). The software has been tested under real world conditions on Army installations (Dortch 2013). The Strategic Environmental Research and Development Program (SERDP) and the Environmental Security

---

\* <http://www.aec.army.mil/Services/Support/RangeOperations/RangeDesignRiskAssessmentModel.aspx>

Technology Certification Program (ESTCP)\* have sponsored several investigations directed at small arms ranges and contamination issues. The Environmental and Munitions Center (EM CX), which is part of the U.S. Army Engineering and Support Center of Expertise based out of the U.S. Army Engineer Districts, Huntsville, AL and Omaha, NE Districts, assists the U.S. Army Corps of Engineers and others in environmental remediation, munitions response, and compliance programs.

### **3.2 Natural resource technology/techniques**

Few studies have investigated natural infrastructure impacts associated with small arms ranges on military bases. Some initial work has been done on the impacts of military training on TES downrange of active small arms ranges (Delaney et al. 2011a,b), loss of sensitive/beneficial habitat (Walker and Wang 2014), and erosion/fire occurrence due to weapons training (Beavers and Herron 2015). Funding for such work has come from sources such as SERDP and the DoD Legacy Program, and the individual Services.

Additionally, installations have repurposed survey techniques such as forest health surveys (Applegate et al. 2005) to document physical impacts downrange. The Legacy Resource Management Program, managed by the Deputy Under Secretary of Defense for Installations and Environment, has invested in the Tracer Ignition Minimization (TIM) Tool developed by Colorado State University (Beavers and Herron 2015). The TIM tool models the fuel load conditions that can promote wildfires caused by live fire training. This tool includes components that examine landscape spatial patterns that may in turn relate to bullet fate downrange. The Legacy Program also provided funding to demonstrate the effectiveness of acoustics at detecting overshot munitions in downrange sensitive areas (Delaney and White 2015).

Our informal survey combined with previous research document examples of installation devised monitoring and survey methodologies that help document and quantify bullet impacts. Examples include visual inspections of tree damage, documentation of the presence of expended projectiles, and cloth witness panels that indicate relative direction of bullet paths. The effectiveness of such methods is usually limited due to the need for accessibility to downrange areas, visibility requirements of detecting

---

\*[www.serdp-estcp.org](http://www.serdp-estcp.org)

munitions damage, and the time-consuming nature of surveying large areas for signs of bullet incursion.

### 3.3 Non-environmental technology/techniques

Training range managers frequently conduct line-of-sight (LOS) examinations to take advantage of existing topography to improve range safety, minimize berm construction costs, and contain bullets. Range officers estimate this zone based on the type and quantity of munitions, the proposed location of the range project, type of vegetation, and the downrange terrain (T. Marston, Fort Benning Wildlife Biologist, pers. comm.).

Tools for range design and range safety operations exist within the military services. These delineate SDZs and incorporate facility features (e.g., earthen berms, targets). The Range and Training Land Program Mandatory Center of Expertise (RTLPM CX) is part of the U.S. Army Engineering and Support Center, based at the U.S. Army Engineer District Huntsville, AL. This program assists the U.S. Army Corps of Engineers in the planning, design, and construction of Army training ranges and facilities.

The most easily accessible and relevant tool in this area is the Range Managers Tool Kit (RMTK) (Swearingen 2006). RMTK is software that provides a set of spatial tools to rapidly estimate military live-fire training or testing noise, as well as perform line-of-sight (LOS) and SDZ analyses. Data and methods in the DA PAM 385-63, Range Safety (HQDA 2003) determine the standard SDZ. SDZs demarcate areas having more than an infinitesimal probability of exposure to lethal danger from live-fire activities. Both U.S. Marine Corps (USMC) and the U.S. Army use RMTK. Models within RMTK that consider LOS and SDZ are relevant to the topic, as they can be re-employed to calculate the bullet spatial occurrences, especially of interest are those models originating from the United Kingdom-Ministry of Defense.

In addition to modeling tools, best management practices and technical sources (e.g., Department of Army Pamphlet (DA PAM) 385-63 *Range Safety*; HQDA 2003) are also important when considering methods of predicting/quantifying fate. Management practices/methods such as berms (most commonly earthen), and specialty materials such as SACON™ (Hudson, Fabian, and Malone 1999) and the fireproof bullet-trapping medium GEL-COR™ (Tom and Weiss 2006) may affect munitions footprint.



## **4 Future Technologies**

### **4.1 Remote sensing and 3-D visualization**

Remote sensing offers a pathway toward better analyses of downrange munitions impacts. Thermal infrared and LiDAR can perform sampling of downrange areas without significant needs for access, and can provide volumetric images of the vegetation (e.g., Tweddale and Newcomb 2011, Tweddale et al. 2014). Repeated sampling can quantify vegetation changes over time, a common symptom of ineffective berm design.

Computer Aided-Drafting/Geographic Information Systems (CAD/GIS) data layers for the installation boundaries, infrastructure, firing ranges, and terrain/vegetation are commonly available. Working from such data, 3-D visualization and line-of-sight analyses offer an approximate understanding of protective berms, the physical layout of downrange areas and management of ricochets. Modeling ballistic trajectories allows the improved understanding the effectiveness of berms and other landscape features on projectile fate (Delaney et al. 2011b).

### **4.2 Acoustical monitoring**

The future of noise monitoring on military installations lies in the ability to acquire data quickly using automated systems placed within the environment. ERDC is in the process of developing a prototype noise assessment toolkit, RAPID (Real-time Adaptation, Prediction, and Informatics for Dynamic Military Noise Environments) that uses data from automated noise monitors to provide installations with high quality data and real-time assessment of installation noise impacts (Dr. Edward Nykaza, pers. comm.). If this technology and associated techniques prove to be effective, its use to monitor and detect downrange munitions into sensitive areas real-time would enable resource managers to more proactively respond to future problems.

## 5 Benefits

Successful understanding of bullet fate and vegetation reduces the probability of conservation and compliance related impacts on the lifecycle of range operations (e.g., compliance with Endangered Species Act of 1973 (6 USC 1531 et seq.) the National Environmental Policy Act of 1969 (PL 91–190). Natural infrastructure damage (e.g., munitions damage to forest resources, critical habitat; see Appendix A, Figure A-5) can be detected and forestalled through remote sensing, 3-D visualization and acoustical monitoring.

Controlling or monitoring impacts involves benefits throughout the range lifecycle, including:

1. Improved range design (i.e., berm engineering and effectiveness, firing angle, firing and target box locations);
2. Improved understanding of munitions fate and deposition during training operations; and
3. Mitigation of impacts to downrange natural resources, including:
  - a. physical consequences (e.g., bullet strikes on trees which can impact nesting or foraging habitat for TES and species-at-risk);
  - b. physiological effects (e.g., stress induced response to military training by wildlife species of interest); and
  - c. economic damage (e.g., loss of marketability of forest products).

DoD would benefit in a number of ways:

1. Military natural resource managers need such information on impacts within sensitive areas downrange of live-fire ranges, for making effective management plans. Effective management of wildlife populations is necessary to meet conservation and regulatory requirements.
2. The information on impacts is also necessary to adapt land management plans in balance with changes over time of military training practice. Current methods for documenting live-fire training operations employ a computer based system (i.e., Range Facility Management Support System [RFMSS]) in which military units enter the planned number of rounds fired per training event. More closely connecting operations and to impacts allows for better management strategy.
3. Acoustical techniques can assist documentation of bullet ingress into downrange areas.
4. Acoustical data from downrange areas can help identify ranges from which bullet ricochets originate, and help distinguish the types of ricochets.

Quick identification of ricochets would lessen the potential for harm to persons or the environment.

5. Line-of-sight and trajectory analyses, when supported by vegetation impact assessment, can indicate whether berm construction is necessary or effective. When berms are not sufficient, bullet traps can prevent bullets from overshooting ranges, and these can be evaluated with similar analyses.
6. Line-of-sight and trajectory analyses can play an important role in the cost-benefit considerations. Although logistical considerations (the size of the range, berm specifications, and availability of resources and personnel to construct the berm [heavy equipment, trained operators, and on-site fill material]) can combine to make the costs to construct berms prohibitively high.
7. Guidance/supporting data and associated field techniques are applicable to all military installations and branches of DoD (e.g., Air Force, Marines, and Navy) where similar issues are present for other species of interest.
8. Biological information available from acoustical data (e.g., species presence, reproductive status, and animal response behavior) could be useful for installations in preparation of their Integrated Natural Resource Management Plans.

## 6 Conclusions and Findings

Based on the responses to this inquiry, downrange areas from small arms ranges often have species of interest and habitat supporting those species. Projectiles escape the containment area primarily through overshoot and ricochet. Small arms munitions fate and impacts in these areas is important. Potential impacts on natural resources include: (1) constituent contamination, (2) wild fire ignition, (3) damage to critical habitat, and (4) impacts on listed species. Because these areas are within, or nearby to the SDZ, physical access for performing surveys is limited.

There is a need for tools and guidance to address the issue of small arms munition impacts on natural resource infrastructure within sensitive downrange areas. Concurrently, there is a need to promote awareness of potential impacts on sensitive habitat or species downrange. Only two projects are known to have performed field work devoted exclusively to the downrange area within TES habitat on Army installations (Delaney et al. 2011a,b).

Bullet containment devices (berms, traps, and backstops) at small arms ranges is the main method of controlling the movement of ammunition downrange. The emphasis placed on containment sometimes depends on whether the downrange area has viable habitat for TES. This and other cost/benefit explorations could benefit from LOS and trajectory analysis, combined with options for bullet containment.

Each of the techniques of remote sensing, 3-D visualization, and acoustical sensing showed merit for evaluating the impacts, even when access to the sites was limited. None of them, however, offers a comprehensive assessment, and there exists no set of best practices.

Acoustical techniques offer a viable method for quantifying bullet intrusions into sensitive downrange areas (Delaney et al. 2011a,b). Experimental development and additional field scenarios could improve the effectiveness and specificity of acoustical techniques. Experience with bermed and unbermed ranges would expand the knowledge base on projectile flight and ricochet acoustics. Long-term recording systems placed at multiple locations recording over multiple days would be possible and practical. Long-term systems indicate range utilization and noise in rela-

tion to biological activities of some types of species. Techniques and procedures are being developed to expedite data collection and analysis of military munitions fire in near real-time (i.e., the RAPID program).

## Acronyms and Abbreviations

Term	Definition
BMP	Best Management Practice
CAD	Computer-Aided Design
CASI	Center for the Advancement of Sustainability Innovations
CERL	Construction Engineering Research Laboratory
DA	Department of the Army
DNR	Department of Natural Resources
DoD	U.S. Department of Defense
DTC	U.S. Army Developmental Test Command
EM CX	Environmental and Munitions Center
EPA	Environmental Protection Agency
ERDC	U.S. Army Engineer Research and Development Center
ERDC-CERL	Engineer Research and Development Center, Construction Engineering Research Laboratory
ESTCP	Environmental Security Technology Certification Program
GIS	Geographic Information System
LiDAR	Light Detection and Ranging
LOS	Line of Sight
MC	Munitions Constituents
RAPID	Real-time Adaptation, Prediction, and Informatics for Dynamic Military Noise Environments
RCW	Red-cockaded Woodpecker
RFMSS	Range Facility Management Support System
RMTK	Range Managers Toolkit
RTLTP MCX	Range and Training Land Program Mandatory Center of Expertise
SACON	Shock-Absorbing Concrete
SDZ	Surface Danger Zone
SERDP	Strategic Environmental Research and Development Program
SF	Standard Form
TES	Threatened and Endangered Species
TIM	Tracer Ignition Minimization
TN	Technical Note
TR	Technical Report
TREECS™	Training Range Environmental Evaluation and Characterization System
USACE	U.S. Army Corps of Engineers
USAEC	U.S. Army Environmental Command
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
USMC	U.S. Marine Corps

## References

- Applegate, J. R. 2005. *Down Range Land Condition: Range 05 (10-meter Zero)*. Fort A.P. Hill, VA: Environmental Division, Directorate of Public Works.
- Beavers, A. M., and C. Herron. 2015. *Tracer Ignition Minimization Tool Additional Fuels*. DoD Legacy Program. Project Number 12-374.
- Delaney, D. K., and M. White. Spring 2015. Using acoustics to document and characterize military munitions within downrange sensitive wildlife areas. *Natural Selections*, [https://www.dodlegacy.org/Legacy/Documents/635677289099615778NaturalSelections\\_Spring2015\\_Final\\_highres.pdf](https://www.dodlegacy.org/Legacy/Documents/635677289099615778NaturalSelections_Spring2015_Final_highres.pdf)
- Delaney, D. K., L. L. Pater, L. D. Carlile, E. W. Spadgenske, T. A. Beaty, and R. H. Melton. 2011a. Response of Red-cockaded Woodpeckers to military training operations. *Wildlife Monographs* 177:1-38.
- Delaney, D. K., P. Guertin, S. Tweddale, and M. White. 2011b. *Evaluation of Military Range Berm Effectiveness in Protecting Red-Cockaded Woodpecker Foraging and Nesting Habitat*. ERDC/CERL TR-11-13. Champaign, IL: Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL), [http://acwc.sdp.sirsi.net/client/en\\_US/default/search/detailnonmodal/ent:\\$002f\\$002fSD\\_A\\$SET\\$002f0\\$002f1002669/ada?qu=ERDC%2FCERL+TR-11-13&rt=false%7C%7C%7C\\$SET\\_NAME%7C%7C%7CReport+Number+or+Name+%28digitized+reports%29](http://acwc.sdp.sirsi.net/client/en_US/default/search/detailnonmodal/ent:$002f$002fSD_A$SET$002f0$002f1002669/ada?qu=ERDC%2FCERL+TR-11-13&rt=false%7C%7C%7C$SET_NAME%7C%7C%7CReport+Number+or+Name+%28digitized+reports%29)
- Dortch, M. S. 2013. *Application of TREECS to Small Arms Firing Ranges at Fort Leonard Wood, MO*. ERDC TN-EQT-13-2. Vicksburg, MS: U.S. Army Engineer Research and Development Center (ERDC), [http://acwc.sdp.sirsi.net/client/en\\_US/search/asset/1032584](http://acwc.sdp.sirsi.net/client/en_US/search/asset/1032584)
- Fabian, G. 2006. *Army Small Arms Training Range Environmental BMP Manual*. DTC Project No. 9-CO-160-000-504. Aberdeen Proving Ground, MD: U.S. Army Environmental Command (USAEC) and [http://gpmuellerdesign.com/portfolio/multimedia/itam\\_cd/documents/Technology/Army%20Small%20Arms%20Training%20Range%20Environmental%20BMP%20Manual.pdf](http://gpmuellerdesign.com/portfolio/multimedia/itam_cd/documents/Technology/Army%20Small%20Arms%20Training%20Range%20Environmental%20BMP%20Manual.pdf)
- Gerald, J. A., M. S. Dortch, B. E. Johnson, and M. R. Fontan. 2009. *Establishment of the TREECS Platform: A Survey of Existing Tools, Portals, and Frameworks*. ERDC TN-EQT-09-2. Vicksburg, MS: U.S. Army Engineer Research and Development Center (ERDC), US Army Developmental Test Command, [http://acwc.sdp.sirsi.net/client/en\\_US/search/asset/1003259](http://acwc.sdp.sirsi.net/client/en_US/search/asset/1003259)
- Headquarters, Department of the Army (HQDA). 2003. *Range Safety*. Department of the Army Pamphlet (DA PAM) 385-63. Washington, DC: HQDA, [http://www.apd.army.mil/pdf/files/p385\\_63.pdf](http://www.apd.army.mil/pdf/files/p385_63.pdf)

- Heath, J. C., L. Karr, V. Novstrup, B. Nelsor, S. K. Ong, P. Aggarwal, J. Means, S. Pomeroy, and S. Clark. 1991. *Environmental Effects of Small Arms Ranges*. Naval Civil Engineering Laboratory (NCEL) (currently the Naval Facilities Engineering Command [NAVFAC]) Technical Note N-1836. Port Hueneme, CA: NCEL.
- Hudson, K. L., G. L. Fabian, and P. G. Malone. 1999. *Demonstration of Shock-Absorbing Concrete (SACON) Bullet Trap Technology*. USAEC Report No. SFIM-AEC-ET-CR-99017. Fort Sam Houston, TX; U.S. Army Environmental Command (USAEC).
- Interstate Technology & Regulatory Council (ITRC). 2005. *Environmental Management at Operating Outdoor Small Arms Firing Ranges*. Washington, DC: ITRC, [www.itrcweb.org/guidancedocuments/smart-2.pdf](http://www.itrcweb.org/guidancedocuments/smart-2.pdf)
- Swearingen, M. 2006. *The Range Managers Toolkit (RMTK) Noise Tool*. ERDC/CERL TR-06-15. Champaign, IL: ERDC-CERL, [http://acwc.sdp.sirsi.net/client/en\\_US/search/asset/1002539](http://acwc.sdp.sirsi.net/client/en_US/search/asset/1002539)
- Tom, Joe G., and Charles A. Weiss, Jr. 2006. GEL-COR™. Fact Sheet, <http://gsl.erd.usace.army.mil/pdfs/gel-cor.pdf>
- Tweddale, S., and D. Newcomb. 2011. Landscape Scale Assessment of Predominant Pine Canopy Height for Red-Cockaded Woodpecker Habitat Assessment Using Light Detection and Ranging (LIDAR) Data. ERDC/CERL TR-11-8, [http://acwc.sdp.sirsi.net/client/en\\_US/search/asset/1002666](http://acwc.sdp.sirsi.net/client/en_US/search/asset/1002666)
- Tweddale, S., P. J. Guertin, and G. Z. Gertner. 2014. Remote Sensing Protocols for Parameterizing an Individual, Tree-Based, Forest Growth and Yield Model. ERDC/CERL TR-14-18, [http://acwc.sdp.sirsi.net/client/en\\_US/search/asset/1036582](http://acwc.sdp.sirsi.net/client/en_US/search/asset/1036582)
- Walker, J. L., and G. G. Wang. 2014. *Managing loblolly pine (*Pinus taeda*) Stands for the Restoration of Red-cockaded Woodpecker (*Picoides borealis*) Habitat*. Final Report. SERDP Project RC-1474, <http://www.dtic.mil/cgi-bin/GetTRDoc?Location=U2&doc=GetTRDoc.pdf&AD=ADA606951>



## Appendix A: Effects of Bullet Strikes on Fort Benning and Fort Stewart, GA.

Figure A-1. Initial horizontal trajectory of a tracer bullet fired at a 600 m target at the Malone 5 range on Fort Benning, GA.



Figure A-2. Path of the same tracer round fired in Fig. A1 that ricochets after hitting the ground near a 600 m target at the Malone 5 range on Fort Benning, GA. Note the upward trajectory of the bullet.



Figure A-3. A formerly active Red-cockaded woodpecker nest tree killed in by wildfire in 2010.





Figure A-4. Different types of tree damage caused by bullet strikes on Fort Benning and Fort Stewart, GA. Multiple forms of tree damage was observed: small scars (A), large cambium cuts (B), bark bullet strikes (C), nodules (D), and broken branches, leader or stems (E).

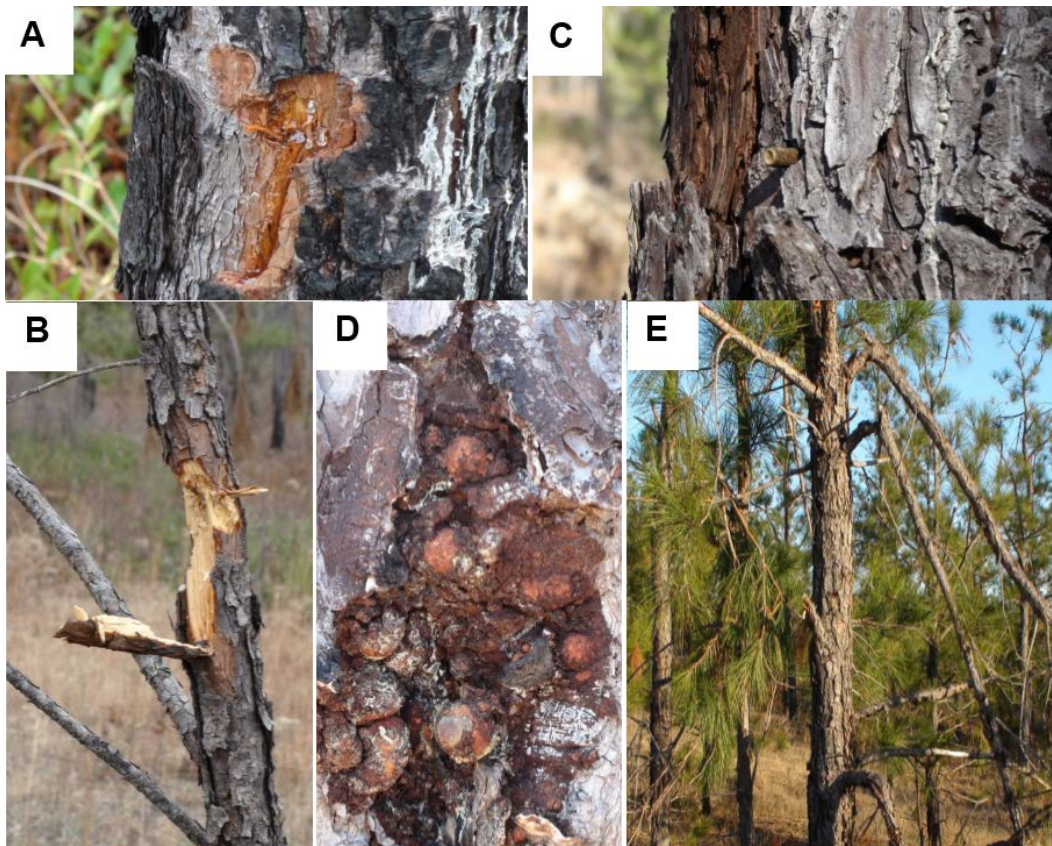


Figure A-5. Bullet strike into the bark of a Red-cockaded Woodpecker (RCW) cavity tree approximately 1810 m downrange from the firing line at Malone 5 on Fort Benning, GA.



REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.					
1. REPORT DATE (DD-MM-YYYY) 17-02-2016		2. REPORT TYPE Final		3. DATES COVERED (From - To)	
4. TITLE AND SUBTITLE Assessment of Small Arms Munitions Impacts on Natural Infrastructure in Sensitive Downrange Areas on Military Installations				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT	
6. AUTHOR(S) David Delaney, Patrick Guertin, Michael White, and Richard Fischer				5d. PROJECT NUMBER 611102AH68	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Engineer Research and Development Center (ERDC) Construction Engineering Research Laboratory (CERL) PO Box 9005, Champaign, IL 61826-9005				8. PERFORMING ORGANIZATION REPORT NUMBER  ERDC/CERL TN-16-1	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Engineer Research and Development Center (ERDC) Center for the Advancement of Sustainability Innovations (CASI) PO Box 9005 Champaign, IL 61826-9005				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT  Large areas of high-quality terrestrial natural infrastructure exist downrange of small arms training ranges on Department of Defense (DoD) installations. Live-fire training has caused concern to regulatory agencies because of the potential impacts on natural resources, and to safety concerns expressed by adjoining landowners. This report investigated methods to quantify the number of bullets that escape the containment berm and terminate down range. Inquiries were made among Natural Resource peers and reviewed methods that address bullet fate on ranges. Responses to the inquiries indicate that Natural Resource personnel on military facilities, as well as those at other state or federal agencies, do not have adequate tools or guidance to address the potential issue of smalls arms munition impacts within sensitive downrange areas. It was concluded that both acoustical and visual techniques have potential for quantifying bullet overshoot and ricochets into sensitive wildlife areas, though neither approach is sufficiently developed. Acoustical techniques can quantify bullet intrusions into downrange areas. Visual and 3-D analyses can estimate the likelihood for intrusions downrange, but only more comprehensive development and testing would reveal the effectiveness of these techniques at ranges under different field conditions.					
15. SUBJECT TERMS Center for the Advancement of Sustainability Innovations (CASI), munitions, installations, land management, small arms fire, firing ranges					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT  SAR	18. NUMBER OF PAGES  28	19a. NAME OF RESPONSIBLE PERSON
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified			19b. TELEPHONE NUMBER (include area code)